**Introduction to Helicopter Aerodynamics and Dynamics**

**Prof. Dr .C. Venkatesan**

**Department of Aerospace Engineering**

**Indian Institute of Technology, Kanpur**

**Lecture No. # 02**

For, flying the helicopter we call it collective pitch, tail rotor pitch.

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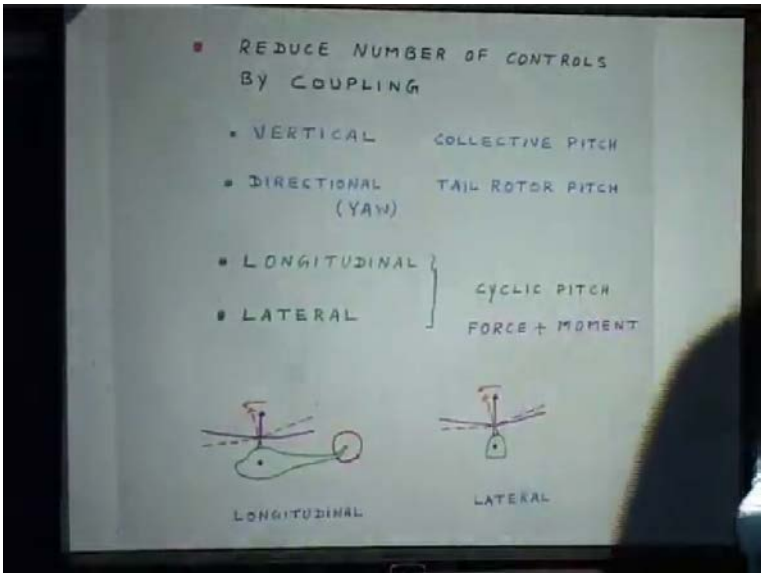


And we call them as cyclic, because then, it is split into longitudinal cyclic, lateral cyclic. But, then when you give that these commands, basically what pilot does is? He is just moves the stick and the effect of that motion of the stick to the rotor system is basically initially the rotor disk may be horizontal. And when he gives longitudinal, the disk may tilt with respect to the shaft.

So, initially the disk is like this (Refer Slide Time: 01:11), then it tills; as a result, it develops a forward component of the rotor lift force and that will move the helicopter forward. But, that will also give a movement about the CG therefore, it will pitch. So, these two, you we cannot decouple. Similarly, you can do lateral that means the tilting it this way, which implies he can fly in any 360 degree. This is very primitive way of explaining, the helicopter controls very simple way.

But, in reality, all of them are coupled. Because, if you do one in the sense, if I want to climb up very simple; but, because of the increased lift or we call it thrust, there will be a torque will increase; as a result, the helicopter will start turning that means yaw has to, he has to control.

Similarly, when you want to do longitudinal, because of the coriolis, centrifugal, all those affect that gyroscopic effect of the rotor, he will get the role which is undesirable, but you cannot help it that means he has to keep on adjusting. If he wants one, he will get an undesirable response, and he has to compensate for that. That is why, helicopter flying is more difficult.

So, first the pilot gets trained in fixed wing flying, all the helicopter pilots. They first go through flying in the fixed wing then they come to helicopter training. But, here the flying is different. So, they go through another training and these pilots are then helicopter pilots that is all. And they have to get the hang of how to fly, because his hands, his legs everything is engaged in the vehicle dynamics.

Now, you see basic and another thing is the helicopters are unstable, both statically as well as dynamically. So, the pilot has to keep on, he has to fly it is not that, he can take his hands and legs off from the system and the vehicle will beautifully fly, no it does not happen that way. So, he is in the loop to fly the helicopter.

Suppose, you say you do not want the pilot, like now you says autonomous. That means some other system should be inside to take care of the control, that is where automatic flight control systems; basically that is to relieve the load that is given to the pilot, but those are expensive then you increase the complexity. That is why in the design of helicopter usually, if you design the vehicle, the basic vehicle without any of this close loop controls, if the system behavior is very good, then the effort required to make it better is less.

But, if the basic system is not very good, then the effort required to fly by the pilot is more. That is why when I spoke to some pilots he said, our job is not just to fly the vehicle. But, even though a pilot has to fly the vehicle, it is not that he has to only fly, because he has to do other tasks; like other tasks means, may be taken a (( )) if it is a attack helicopter, he has to operate certain other things. He will look through various other environment that is why his work load is more; whereas, if he is always concentrating on flying, then he cannot do the other work.

So, the developments of see them, I would say the in the helicopter field is towards these directions; how do you reduce the pilot work load? And then, how do you reduce noise? How do you reduce vibration? How do you increase the capability of the helicopter? There are several directions.

And the gap between theory and experiment, that is still there is a big gap. What do you measure? And what you theoretically calculate? There is a gap; and how do you fill it up? That is were the research, all the research is going towards this direction and with the technology improvement. Can I replace some rotor blades with metal rotor blades with composite materials, and the cockpits you will have all sorts of meters. Now, remove all those meter, have a glass carpet they say just a simple display, pilot can push whatever he want, it will be displayed.

So, the technology improvement is in those directions. But, still where these scientist, there is a lot of problems enormous number of problems exist in helicopters, even from a research point of view. So, you have learnt about these basic controls.

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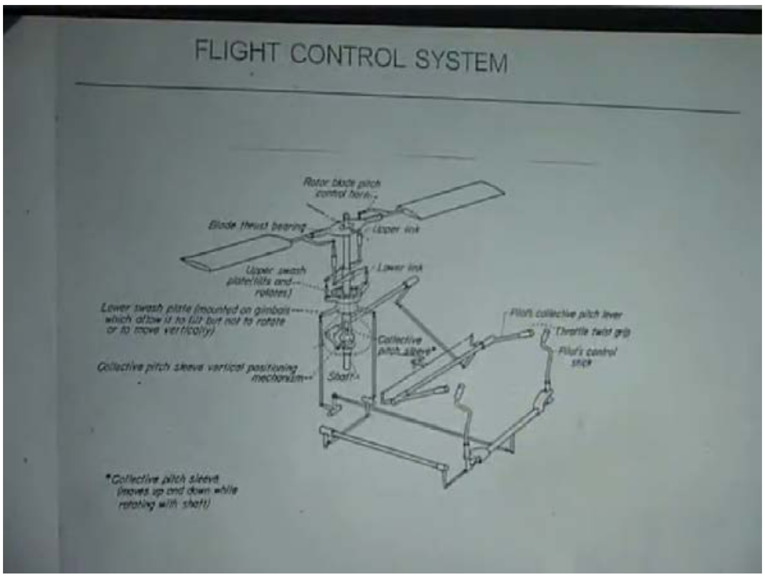


Now, I will give you a schematic of how these controls are this requires a little explanation more. See, this this is for to this particular lever, we call it the collective, that is when he moves what is he really do it, because you say we have given the pilot a stick on the left hand and a stick in the front, and pedals for the leg. But, when he moves what really happens? What is that he is controlling? So, that is by this diagram, I will briefly explain because this is important, when we go for the next stage. When the pilot moves this stick up, what he does is? Through a mechanical please understand, mechanical and hydraulic system today, there is something called a swash plate; please note, this is a new terminology which you do not see in air craft.

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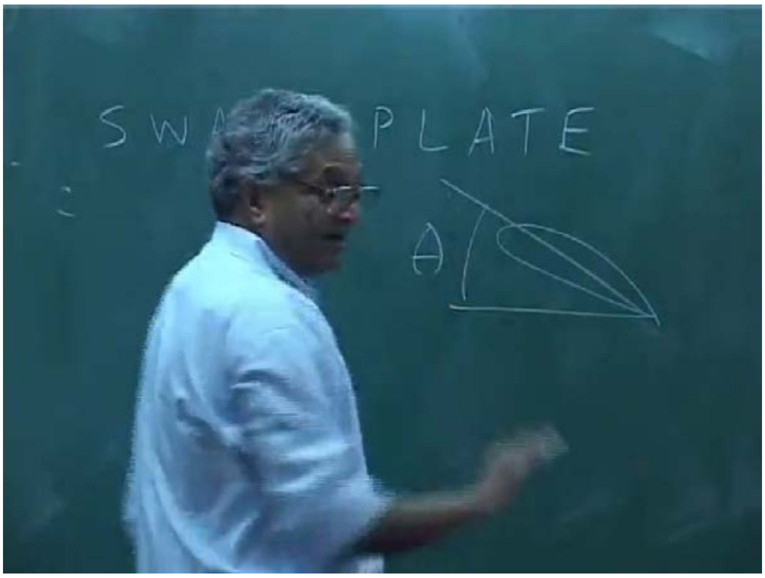


Why what is this, I will show a component which we have. Because, the pilot is sitting in the non-rotating frame he is in the non-rotating frame, the blades are in the rotating frame, you have to transmit, the control from non-rotating frame to the rotating frame right. Now, the control to the blade is simple, because we all know we are all from aeronautics, we have only aerofoil; what you can do at the most to an aerofoil? You change the this angle, which angle of the blade you change that is it, you have no other control.

Now, you may ask, whether RPM is controlled? In big helicopters, RPM is regulated you do not vary the RPM for flying. But, pilot has some control over the changing the RPM little bit, but he always keeps the RPM at a fixed value, that is by like your motor cycle through this he holds it and he can turn it.

That means, engine throttle increases a little bit, but he cannot change it to any value he likes, it only with in a zone, because he will have a meter that tells you what is the rotor RPM and what is the engine RPM, please understand. Now, you see in helicopter whatever we are going to develop from now on, in terms of the equations of motion or thrust power anything, rotor RPM is a fixed quantity; it is not a variable quantity that is in helicopters.

Now, you imagine if you want to make a small, all these autonomous that microware vehicle everything, there you may vary the RPM; see the control may be through RPM control, but here RPM is fixed. What you have control is only the pitch, pitch input. Now, what that pitch input? Because, we have several blades on the rotor from two and more, we will come to the rotor system later. When the pilot pulls up, what he does is? This is the swash plate mechanism; it has two components, one is a non-rotating, another one is a rotating with some Baring in between that is all.

And that system I do not know whether if I, I will show another picture. But, it is like this, this is actually the swash plate, I do not know whether you can see I do not know how do you put it, this is the swash plate; you see, I can move the inner one you see the inner one can move, and the outer one is fixed. From the outer, the control rods from the outer will go to the pilot that is non-rotating; and from the inner, it will go to the, I do not know whether you can what inner one goes to the blade. So, depending on how many blades you have, you will have a non-rotating non rotating and rotating; this is to pilot, this is to blade. So, the swash plate mechanism has two parts.

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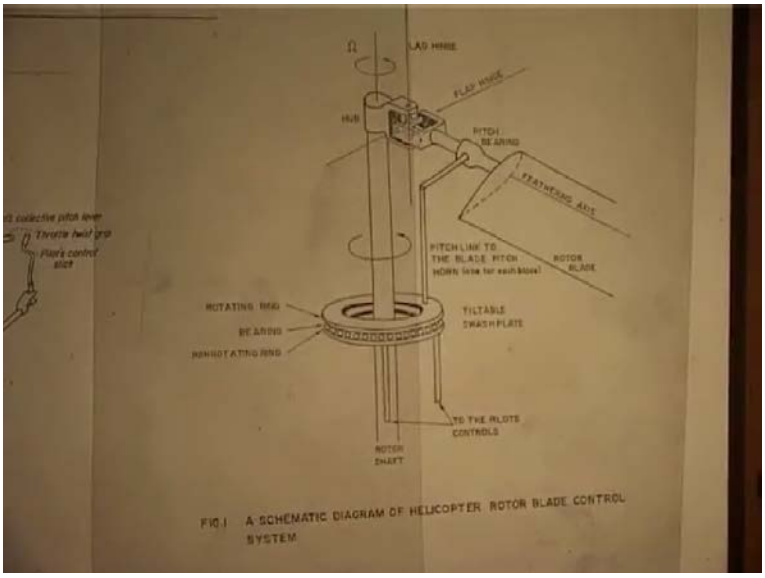


And schematically there is another another picture, which I can show here it will be like this that is very simplistic, because please understand; this is a see as a mechanical system, this is a very beautiful thing. Because people have thought about, how to really design a mechanism through which you control from a non-rotating to a rotating system.

Now, if you want to do some (( )) this is a very heavy system, heavy mechanical weight as a heavy weight; suppose you say, by electrical some wireless beams I control, if you do that, while may be that will become after 50 years that may become retrained. Because mechanical systems still are reliable you follow. So, they still use this, swash plate because, if it goes that is all, the vehicle vehicle is gone.

So, these are all very critical systems of the helicopter flight control system it should never fail that is it. So, you see this is the non-rotating, and this goes to pilot control and above this is the rotating swash plate, rotating ring and this is the control rod. Now, if I move this entire unit up or down, what I am doing is I move this control rod up or down, not only this control rod all the; if I have four blades, every blade will have its own control rod, I move everything simultaneously up or down.

When I do simultaneously up or down, I change my there is a pitch bearing. So, you see what happens? This, if I move it is going to rotate about the pitch axis. So, all the blades will experience same change in pitch angle, I am not using the word angle about act, I am only using pitch angle; please understand, because angle about act we will learn later, because it is a too complicated, pilot gives only pitch input.

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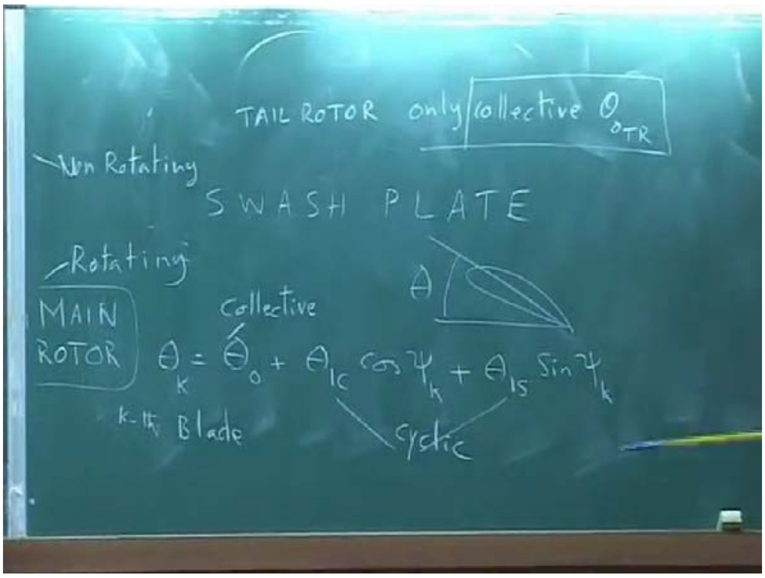


So, now let us write the pitch to the blade as data 0, this is to any blade K represents k th blade, we always used a subscript K to represent k th blade. You can say, k th blade, I put a 0 to indicate that this is a collective pitch input, this is called collective; collective pitch input pilot gives, which means he moves the stick up, because it is collective lever is up, this lever this swash plate will go nicely up or down, up normally it goes up, depending on where this control rod this it is in front or back please understand.

I can have this rod in front of the blade or back of the blade, depending on I move it this way or I pull it. Basically, he moves up and down is collective; if he moves it up, which angle up all the blades in the rotor system change simultaneously; there is no difference, all the blades will experience same pitch change.

Now, let us go to the this stick (Refer Slide Time: 17:21), this is this control stick for cyclic, this is the cyclic stick, I would not if he moves forward, there is a lot more inside of this, vehicle will fly forward please understand that is all. How the swash plate will move, I will say there is some ringing done will at present we will not bother about the ringing; what it does is? Swash plate is instead up moving up, it will tilt; it will tilt in the sense, the swash plate instead of up it will tilt like this (Refer Slide Time: 18:12). You can now tilt it any plane please understands right.

Let us assume, it is tilted about some axis and it is tilted like this (Refer Slide Time: 18:26). Now, as the blade goes round and round, what happens? This control rod keeps going up and down; and when it goes up and down, it goes up and down in one cycle. So, we call it one per revolution. What happens? The pitch angle changes once in a revolution. Now, you can tilt it in this about this axis or you can tilt it about this axis, swash plate. So, these are the two axis tilt, you can look.

Now, if you tilt in these two planes independently, which mean by suitable adjustment I can tilt along any axis you follow; because, if I can tilt in this axis, if I can tilt about this axis that means I can suitably combine I can tilt like this, I can tilt like this; that means this is I can go in this fashion, in this fashion any fashion. So, that you called cyclic pitch input. And it varies once in a revolution depending on where the blade is. Because, if you say I tilt like this, if the control rod is here then no change, because whereas, if my control rod is here, if I tilt it goes down and the control rod at the back goes up. So, depending on the location of the basically control rod, but we do not write control rod in pitch angle, we write it like this.

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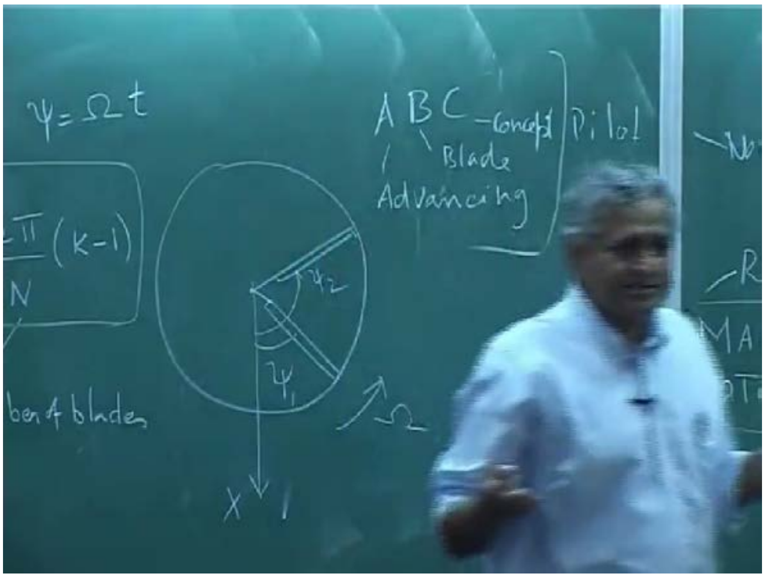


Now, I will represent what is cycle? You take this as your rotor disk and this is my, this is the standard reference, this is to the tail you are viewing the rotor disk from top. This is my rotor omega and the rotor blade can be in this is called psi, but if it is a k th first blade which is psi 1; if it is a second blade, you will have psi 2 like that.

So, k th blade it will be psi k. That is why I put psi k, the azimuth location of the blade. Now, please understand we do not represent the azimuth location of the control rod, control rod may be in some other location, because of this tomorrow I will, when you come to the lab, I will show you. But, we represent mathematically a, my pitch angle varies cyclically this is these two are cyclic inputs.

So, you have collective, I call them cyclic, I am not now assigning whether it is a longitudinal cyclic or lateral cyclic please understand; then that requires dynamics, what do you call it as longitudinal, what you call it as lateral? You have to know a little bit more about the dynamics right now they are called cyclic inputs. And k represents the azimuth of the k th blade.

So, now, if you have that is why this is written, psi this is the first plate you say, 2 pi over N, N is the number of blades in the rotor system, number of blades. Because, if it is the first plate this is 0 like a psi 1, psi 1 is psi that is this is; if there are two blades, this will be pi; so, you add 90; if three blades, it will be 120; four blades, 90 degree. So, this is the general expression for for the location of the k th blade, azimuth.

And this is (Refer Slide Time: 24:18), the psi is what? That is the angle of the first plate, but that is nothing but, omega t right; omega is the rotor angular velocity got it. Now, you have only these three inputs pilot gives. Now, please understand this is the input to main rotor, sorry because I am now restricting this to one main rotor, one tail rotor system.

Now, you please imagine, if you have a two contra rotating rotors, there is no tail rotor, if you have one rotor in front, one at the back that is tandem; there is no tail rotor, only thing is one is the main rotor, another one is also look like a main rotor both are horizontal rotors. Now, the controls as well as the aircraft is concerned, in the helicopter field, this is what, it is not that when you have two rotors, pilot may give collective pilot may give cyclic to both, but he will have only this control.

Now, the you imagine for a, that is why mechanically simple is the single main rotor, single tail rotor. Because, tail rotor the pilot puts the pedal, you will have a pedal here (Refer Slide Time: 26:13), he will somewhere and he will act and that goes to the tail rotor and tail rotor you have only collective. So, please note, tail rotor only collective.

So, we call it theta 0 tail rotor. Now, you see four controls, this is for a single main rotor, single tail rotor, three for main rotor one for tail rotor.

Now, if you have a tail I am not going to be like this, I want to build two two rotors let us say contra rotating one above the other. One above the other, if I do then makes a little tricky, you cannot represent it in this, because there is no tail rotor. Then you always talk about, what motion you want? If you want to climb up, you give collective; if you want to fly forward or sideward, you give cyclic; but, if you want to turn your heading, then you give yaw that is all, that you may do by a differential mechanism between the two rotors.

Because, if one rotor produces a little less torque than the other rotor, because they are all contra rotating, please understand both do not rotate in the same direction, when you have two rotors; whether it is a contra rotating, one below the other or it is side by side, or one behind the other.

Now, you imagine I say hey, what are the controls I have to give to generate motion of the helicopter? Collective you give then, when you give collective, both the rotors collective pitch will increase simultaneously, so you will go up; when you want forward you say cyclic, you can generate by differential collective, because one goes up another comes down, then you will tilt you will go. That is were the control rigging, all the control mechanism becomes different; whereas, if you want to yaw, yaw means I change my heading. In the case of single tail rotor very simple thing, change the pitch angle of the tail rotor. So that, I increase or decrease my force; so, as a result I will yaw very simplistically.

Now, imagine, if you have different different types of rotor system, in the sense rotor configurations, helicopter configurations helicopter configurations not rotor, whether it is a contra rotating, one main rotor one tail rotor or whether you have tandem configuration or side by side configuration; please understand, the mechanical linkages in those cases, all the transmission becomes complex that becomes a little difficult.

I want you to read that how they control those helicopters configurations; ultimately you have to do this you find they are more complex systems. So, that is why mechanically simple is single main rotor, single tail rotor. Now, you understand why most of the people, those who have the expertise in manufacturing a particular helicopter configuration they stick to that. Because, today of course Boeing makes tandem that is C H 40, C H Chinook; and only they make, it is did not that every other fellows starts making it. Similarly that contra rotating, the Russians Kamov helicopter there experience and they make.

Of course, US now wants to call the same thing by a different concept; you know this is just is all you know they call it ABC, Advancing Blade Concept. There is nothing fancy except the ABC you call it, Advancing Blade. Because, just last week I think I saw, because this was this particular thing, it is a contra rotating rotor system that is all; there is nothing, only thing is you know sometimes it is fancy to call the new name. So, that people oh what is that, otherwise there is no nothing special.

US started this long time back Sikorsky, but of course they had lot of problems. Because, they thought as we go along a program you will learn, the advantage of something they thought I can get the advantage from both the rotors; but actually, the disadvantage also comes from both the rotors. So, what it they thought they could achieve, they could not achieve and the project was abundant.

But, again I saw just about last week in newspaper, oh they made this helicopter again; they are again trying to do it, but they call it advancing blade concept, but it is nothing but, contra rotating rotors which the Russian Kamov has. But, only the see that is why the technology and the knowledge, once you gain in a particular configuration of a helicopter, please understand particular configuration of a helicopter, the industry does not want to loose it. Because, you have an advantage in manufacturing and you know what problems you will face; and you have address the problem, you have solve the problems.

Even I give you just little story, but it is not a story it is a reality. There was a contract for building that, I think it was apache at that time if I am right. So, that was initially bell helicopter also tried for that, but bell has been manufacturing two bladed rotors initially. So, when the demand for increased weight and other things started coming up, there is that they again gave two bladed. But then, when the attack version there was some advantages, so it went to four blades, because they did not have, then only they started making four bladed helicopters. So, you loose a big contract itself, if you are not experienced in a particular configuration.

Of course, each industry has it is own specialty. Because, apart from theoretical knowledge, the practical knowledge of implementing, manufacturing, proving, is much more tougher; because, any new rotor configuration please understand it takes more than 10 years; when they wanted to change a metal blade to composite blade, metal blade to only blade change, every else is same.

They said, I will replace a in the helicopter, current helicopter whatever is a metal blade, I will remove it put a composite blade, that alone took 10 years please understand just replacement of a blade. Because, the complexities the whole dynamic, the structure, the aero elastic, all the problems you have to, now it is a new set of problems.

So, even today, there is one small article says, still people do not know they changed some metal to composite identical, dynamically it is a dynamically means frequencies everything is same. But, then when they put that rotor, you have a higher vibration, they said, still we do not know that is all the question is; finally we do not know why? ok. So, these things happen I change something, you think everything is identical; but then, when you put there, know the measurement shows it has a higher vibratory levels.

And that because he was an industry person, who was Prouty which I showed one of the books he writes small articles on it; what we call that? That is a magazine, which is called Vertiflite. It is an American Helicopter Society that is a journal; this is a magazine. In that you know small without equation, one article will always come. So, very interesting articles, there is a still we do not know why.

So, there are many unknown things. So, in this course you will stick to one main rotor, one tail rotor configuration; and now you know the input input is collective and cyclic. So, three inputs go to the pilot and sorry to the main rotor, one input goes to the tail rotor. That is all for helicopter controls there is nothing more, pilot gives only these four.

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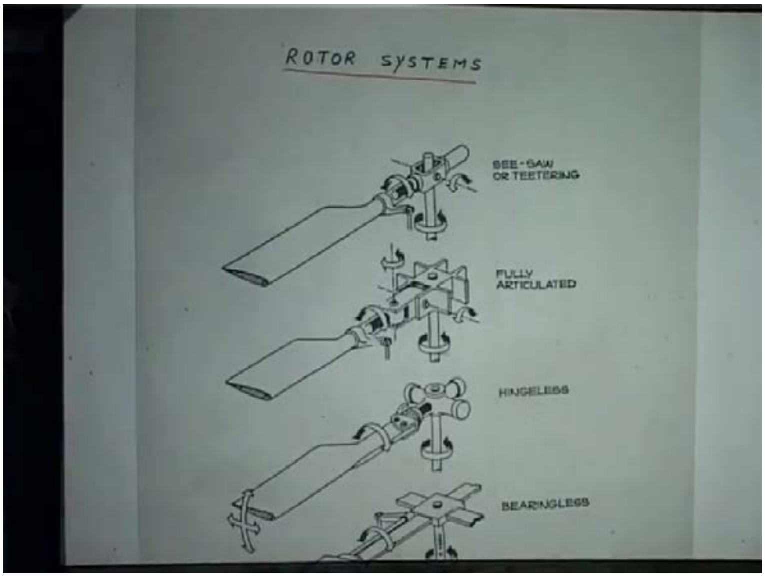


And now, I will briefly go to the rotor systems. It is a rotor system, what do we want? We have a blade, we need to attach it to the hub and then the blade should rotate that is all. How do I attach that is a very simple question; and the type of attachment determines the type of rotor configuration. When I was telling you the history last class, we said that Cierva put a flap hinge that means he deliver, it was a engineering solution for a problem. So, he introduced a physical flap hinge.

And what we need is, now you know that there is a hinge, we also need to change the pitch angle. That means, if I rigidly attach to the hub I cannot change the pitch angle that means I should have a pitch bearing. Now, you see I should have a pitch bearing which will change the pitch angle of the blade. Now, you need these two, you must attach it pitch bearing should be there, but you can have a hinge you may say.

So, now let us look at the now you know what can what you require (Refer Slide Time: 38:45). This is called a see-saw or teetering this is always for a two bladed rotor system. But, tomorrow what we are going to see, which is a two bladed helicopter model that is not this system that is a little different. This is two bladed is see-saw, what is happening is one blade here, another blade here, it is one unit you come and hinge it at the center.

So, hinge is it is like a see-saw. If one blade goes up, other blade goes down do not think about operating another just normal; I have put a hinge here, you see this is the attachment, this is the rotor shaft I put the hub and then attached it and I have a pitch bearing, please understand I have a pitch bearing. Pitch bearing is always required yeah otherwise I cannot change the pitch angle of the blade, is it clear.

Now, this is called the see-saw or teetering rotor. They have only the this flap hinge, because the blade can go like this that is all. So, I have only a flap hinge, which is located at the center of the hub please understand you look at it; the flap hinge is right at the center. This is the see-saw two bladed; this is only for two bladed please understand this is two bladed, four bladed they do not make like this.

Now, you go this is another rotor system, which is called the fully articulated rotor system. In this, you need to have a pitch bearing so that is here (Refer Slide Time: 41:05), that is what this arrow that semicircular arrow represent I can change the pitch angle. Then I have two physical hinges, it has a two physical hinges, one hinge is this that is flap, another physical hinge is here that is lead lag. So, you have two hinges, one bearing. Then, you may ask, what happen to the lead lag here? There is no, no hinge for that, two bladed rotor systems they do not put it.

And you will say, what they will do that design part later, because it is little bit more you have to know to see why they make it like that. Because, it is there is a lot of dynamics involved in that; why you make certain decisions the way. This you will understand as will go along you will say oh this is the reason, this is the reason, this is the reason this is it.

Now, the interesting part is these hinges are not at the hub center. Please understand, they are not at the hub center, they are away from the center of the hub. So, there is a offset, so you call it a hinge offset.

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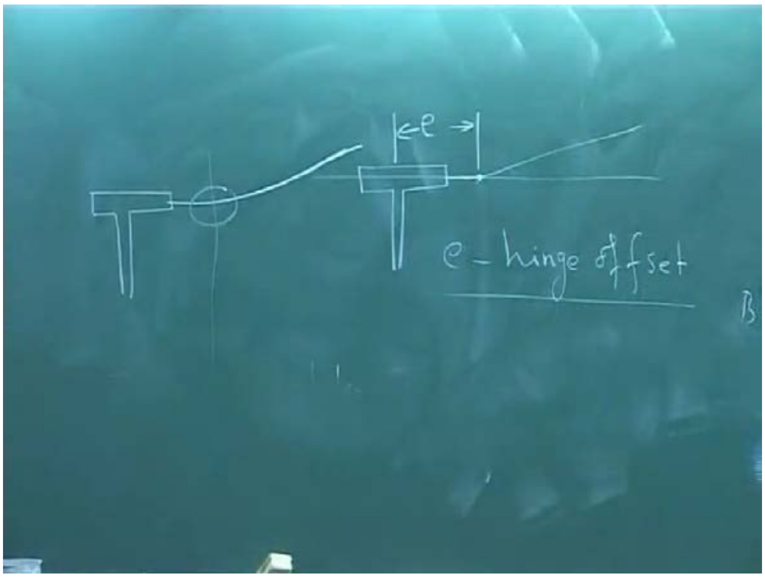


That is you have a, this is like this, you have you put a hinge and the blade goes. So, this distance we call it (( )) the symbol I am using is the same throughout the course I will not change, today I write one symbol and tomorrow another symbol for the same quantity, e is hinge offset. Now, this is for flap motion, flap is that is why I plotted, this is the plane of rotation and the blade is can go like this (Refer Slide Time: 43:31).

And I have put deliberately the offset here, because physically I cannot put when I have four blades I cannot do it or four or three blades; because, you have to attach them, you needs some geometric you have to have some space. So, it is tilted, this is called fully articulated rotor system. All the blades, all the helicopters were built like this; even the attack helicopters you go to Russian helicopters everything till 80's. But of course, some slight change will be there are like this (Refer Slide Time: 44:21).

But, now you know that, when you have a physical hinge, the blade is going up and down, what will happen you have a (( )) problems, maintenance, number of parts everything is high. So, now you see it is from a operational point of a view. You find that articulated rotor systems a good I can attach to everything, but maintenance is is you have to replace parts, replace parts means you have to bring down the whole unit and then remove it, put it annually make it operational.

So, from a design point of view, number of parts you have to lubricate several places. I will show later one picture, then you will get an idea that I we should remove the hinges that was everybody will say, why you put a hinge, I remove a hinge. That means I take the blade simply bolt it, it is good. But then, that is what the hingeless that means there is no hinge right.

I said it easily, just take the blade bolt it, it is easily said then done. Because, if I attach it I must allow flat motion of the blade for flying, because what do I do? When I have a rotor like this, if I want to fly forward I am tilting the rotor disc. How do I tilt the rotor disc? The shaft is straight, please understand really I showed that the shaft is always straight, but the rotor disc is tilted; that means, when the blade comes here it goes up; when it comes to the front, it is down. That means I want the blade to go up and down in a prescribed way; that means I want flap motion.

Flap is completely restricted like a propeller, you have a propeller blade is there in aircraft it is very rigid you attach it, bolt it. Then you have this is rotating, if you want to fly forward what? It will not do this, you have to tilt the entire shaft; in helicopter, the shaft is not tilted only the rotor disc is tilted; that means rotor disc tilt happens, because of flapping motion of the blade. So, the flap dynamics, now you understand flap dynamics means the motion of the blade in out of plane of rotation is important, only by controlling that, the helicopter is flying.

Now, you say I make get hingeless. Hinge is kept to relive the moment, because he said that, if I have a movement I do not want moment, but I want the motion; moment should be that is a good solution, but then this has it problem.

Now, you come here you do not have anything, but of course pitch is there, pitch bearing is required, but how you design? That is why I said, when the technology for manufacturing change from metal to composite. Please understand metal to composite, when we changed, then only the realization of a hingeless blade became possible; because by putting layers of the composite cloth you may call it or prepaid, you can adjust the stiffness of this particular region, I call it this region please understand this region.

What I do is? I do not put a hinge, but I will deliberately make it is flexible there, the blade is made to be flexible at some zone (Refer Slide Time: 48:51), and it is a virtual hinge. This is like a, you want to be the blade to behave like this, but there is no hinge, you follow; that mean the manufacturing you have to, how do you design the blade such that there is a flexibility at the near the root, because this is a root section near the root, but it would have sufficient strength also, because centrifugal force is pulling.

So, the strength and the flexibility the stiffness, so by tailoring by adjusting the layer, they manufacture. Today of course, this is quite common very common; hingeless rotor plates main rotor please understand, now I am saying main rotor blades; even Indian that advanced  like helicopter that is this composite.

Now, you see once this was first started in Germany, they made this helicopter with a composite. Actually, no company would like to be left behind in technology. So, because they see the potential of course, composite has its own problems its own advantages, we will not get into all those issue. Because, if we go that will be another story of its own. What we say is, with the technology development in composites, the realization of a hingeless blade was made possible.

And today companies make hingeless blades. ALH blade is a hingeless that is advanced Indian helicopter blade that is a hingeless composite rotor. That means the manufacturing technology you have to know, the design technology, the design everything you must know. That is why, today this common, composite rotor blade. But, still you have a now you see you have a simplified the rotor system by removing the hinges, but still you have a pitch bearing.

Pitch bearing is also a bearing, now can we remove that. That is the next level of rotor system, which is called the bearingless rotor system; I remove that bearing also you got it. Now, when I remove the bearing then how do I change the pitch? This is a very very primitive schematic; I have a, this is called a flex beam. So, this is called a flex beam, which is a flexible beam in torsion it should be flexible in bending also. Bending means please understand this blade can bend this way, this blade can bend this way lead lag and it should be flexible in torsion; and that was made 80's.

Of course, the concept people at even 1960's please understand. I can have a concept, but then to make it a reality, it may take 50 years, may be you would have written something and that is all. But, somebody else will keep on working working working, now this is the flex beam. And then I will show another picture which is today you they manufacture this blades, but only tail rotor blades.

Tail rotor blades are this; main rotor blade still this is what is used, only one helicopters tested, only one helicopter, lot of complexities. Is a German I think, what is a D G 135 or some helicopter I do not know that numberively; they manufactured, they tested flight tested few years back earlier, they were flying they. Because, now you see I have made the rotor system simple, but the dynamics the manufacturing all other problems.

So, maintenance people it is easy, but they say it is a nightmare for the designer; because, designers do not understand many things. Please understand you may say, I want to do it, I will put the new things and then it will work; industry has to mature to take that concept and then say, they will not immediately buy it. Because in practical implementation, some concepts may not even realizable with today's technology, and the knowledge.

So, one may have to wait for another 50 years to again start. But, these are the rotor configure. Sometimes, people may call it this rotor as a rigid rotor rigid, but it is not really rigid it just for some reference. But, I would not call any rotor as a rigid rotor, because all rotors are flexible. So, for clarity of distinction, you call them as articulated, hingeless, bearing less is it clear. Now, I will just show the real helicopter hub to the schematic; so that, you will have an idea.

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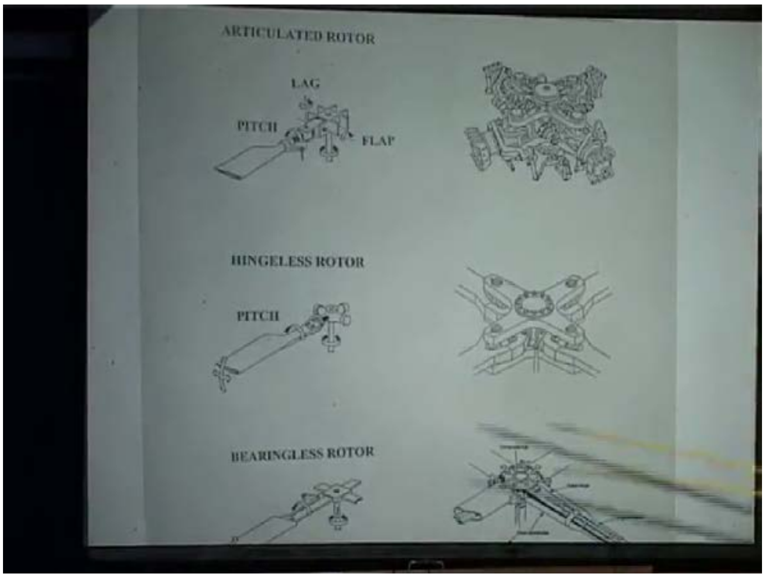


This is the articulated rotor hub, actual helicopter more than 450 parts and about 20 lubrication points; this is the schematic for that. Then hingeless rotor, much much it looks cleaner and simpler, it look simpler. But, the design designer say nightmare it is much much difficult, because later will come to that it much simpler.

And this has 150 parts and may be 1 lubrication; lubrication is basically they put some damper we will go to that later. To this, this is the hingeless, I will explain briefly. See there is a caller, the blade is here, this is the flex beam which is a composite material; what you do is? You twist this beam by pull the lever up and down this is connected to this outer sleeve, so there is a sleeve. What do you do is, this is the inner flex beam which is bolted to the hub; this is like a sleeve, the sleeve goes and joins.

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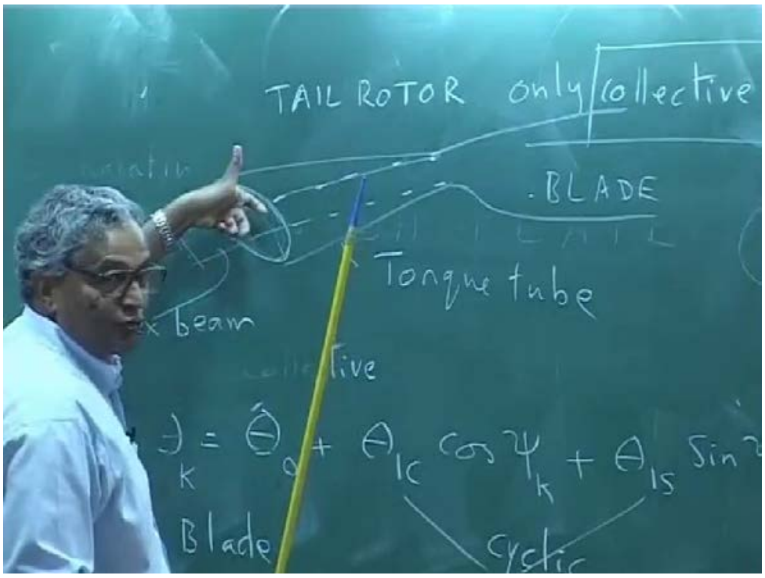


So, it will be like this, if you look at it and here you have that beam will be going, this will come and join. This is the outer, this is called the torque tube, this is called the flex beam and this is the blade. Now, what you do is, you have a lever attached to this, you move the lever up and down; that means this will twist, when it twist? It will twist at this end of this flex beam and then the blade which angle will change.

But, now this is the several path load path, the blade as one control rod, this is the path that what will always be there, and this is the flex beam. And this should be it should take the centrifugal load it is flexible enough to flap, lead lag then twist. So, manufacturing is much much tougher, because you have to know the dynamics and then properly design the entire section.

Now, you see this has the number of parts, it is less than 50 and there is no lubrication for this. So, you see the complexity of articulated in the mechanical side to the very compact clean system of the bearing less. Now, all this things took several years, actually several decades.

Now, you will find, if a company is experienced in manufacturing this, they will stick to it, because it is not easy from here to here. This may again require 10-15 years of developmental work and testing work to replace. That is why they will not everybody is making let us also make, no it is not like that. That means it is your life time, please understand in aerospace technology it is a life time of an individual to concentrate working on that to achieve.

When you start at 25, you will say, this is what I want; may be when you are 50 you may realize that is what now I have made. It is the that period is very long, it is not like every 6 months I will have a new design coming up new product, no. It may be a generation before a new product comes or there may not be any new product, only improvements in the technology that changes. So, this is how the whole thing went yeah.

(( ))

No, there is a fatigue damage see fatigue that is always there yeah. Suppose, you say hingeless blade you wanted to flap up and down right; that means, what? You are actually, suppose you take a pin you want to break it, what you do? You keep doing like this and then it will break that is the fatigue. Here fatigue is very important, but you do not want the blade to break, which means what? You have to design such that, the fatigue life is what is man dated, what is the required; because, I do not know 5000 hours the blade requirement 5000 hours, although blade life after that through it.

Every component may have some life through it out, because I was reading some material now that is very interesting thing. The pitch link rod, what we showed that pitch link, this rod the rod which goes from blade to the hub; that gets all the load, the pitch pitching movement comes as a axial load on that member. Now, you can make it very bulky heavy, so that you will give infinite life, but they do not want infinite life. So, what you do is? You reduce the weight, but life also goes down, you say so many after that remove it.

Now, in the Indian air force this is one of the main things. You know we operate a Russian helicopters plenty air force operates, they all have metal blades and there is this life after that, the blade has to be removed. The blades looks beautiful, there is no visible damage nothing everything is wonderful, but the blade has to be removed; because, the two new blades have to be procured. I think the two new blades whether it is 75 lakhs, now I do not know (( )) blade each blade is 1 crore or pair is 1 crore it is about a crore.

Now, aircraft was we have to keep on import, they have large of blades. So, the whole question is, can you tell us that I can operate at least another 10 percent of that life, life which was given. The manufacturer of the blade will say no, because he can sell more blades right. But, the operator will always say 8, you know I want to extract as much as possible, but without endangering. Because, if anything happened, he will only blame the operator, he will say that, say I told you do not operate but you operated.

Now, what is the scientific way of improving? Because, those blades we have done manufactured by us. Now, there is a program, which is called a life extension. So, they did lot of test, they have given some extension of 10 percent life or something like that. So, these are problems. That is why all this things, there is a 5000 hours say I will not give some of things which are actually you know whatever little I know from the industry thing. Something may be its good, actually as a student is fantastic to know, hey man this is all really amazing, there are problems lot of problems.

So, on one hand somebody will say, I buy is like your bicycle you buy your bicycle you know my father had even I came to me. But, aircraft is not like that, they will say you use it after that through 5000 hours; 5000 hours means whether it is a 5000 hours of operation or they will also specify calendar year after that you through. Suppose, if you do not use, it also you throw it these are these are the money.

Now, you know that, if you make a flying vehicle actually you dictate the economy to a large extend in that sector. Because, it is all high cost items nobody will tell you, how they make it? They will say, we have put all our money, effort, everything to come to this. That is why I said, to come to this blade composite blade, the company took 10 years; 10 years mean, they are not going to come and tell you easily. They will if they tell they will charge you lot of money, enormous amount of money they will charge.

So, these are reality. But, what we learn in this course is of course, some practical thing interesting aspects, because that is to give some, what is that? Interest to the course; otherwise the mathematics involved is really trouble in helicopters. Nobody would like to work in helicopters, because equations are very very long; very long means one term may run to 30 pages.

Then you will say, what are you sure you were deriving it right? You know, because that is the first question will come you write keep on writing; what is that, is it right or wrong? Right or wrong determine only finally, when somebody does an experiment, you say is it close that is what. And that is the reality you will learn you will see. But, what we I will introduce here is very very at a low level.

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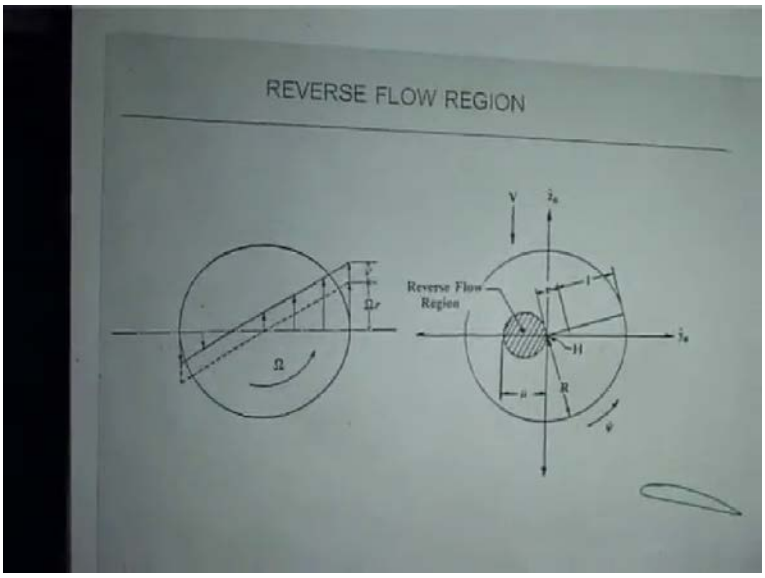


Now, there are some interesting points in the helicopter thing. One one into there are several interesting things, one of them I just want to show this is something which normally does not happen in aircraft, that is why I am putting this. This is the rotor disk, if it is in hover, hover means the helicopter with stationary, wind is not blowing you are just above.

Omega r is the velocity of the blade and that is equivalent to relative air is omega r at any section; it is coming radially that is normal to the leading edge you can say. But, the movement helicopter starts flying forward that is here (Refer Slide Time: 1:07:07), what happened is? This is the forward speed of the helicopter please understand that is nothing to do with the rotational speed of the rotor rotational speed of the rotor.

So, we divide this whole region into two parts. We will get to the math later, right now only explanation I am giving just. What happens is, on the this half where it is rotating it is going into the air, the relative air is actually increased; but, please understand it is not that, because it is going at different different azimuth locations. This V has a fixed re direction; omega r has depending on the azimuth location, velocity is different.

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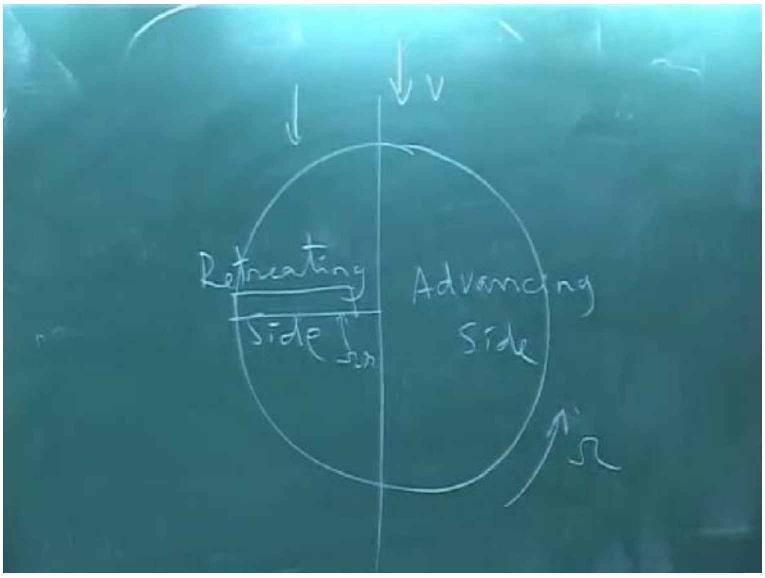


But, when you go to the this half of this, rotor disk actually this is called; you divide the disk into two parts, if this is omega, this is V you call it advancing side. We we will do this again when we do, this is called retreating side; advancing side, retreating side, it is two half. But, in the retreating side what happens? The blade looks like this please understand. This is the leading edge, this is the trailing edge, this is the velocity V coming and this is my omega r.

Now, if V is greater than the omega r that means the flow is coming from trailing edge to the leading edge. And this is this happens in a region and that region depends on what speed you are flying, we will derive that in the course later, how to get this. So, it is very simple geometry, there is nothing more.

And this region is called the reverse flow region that means the flow is coming from the trailing edge to the leading edge (Refer Slide Time: 1:09:29). Whereas, in aircraft that there is nothing like a flow is from the trailing edge to the leading edge, always it is from leading edge, trailing edge.

Now, that is why in aerofoil's for helicopters, when they get the C l, C d, C m, actually they go through full. They plot that, C l verses alpha, alpha going to 360 degrees that means you do one full loop that means flow can come in any direction. And of course, earlier you can neglect it in a sense ok and there is because there is a hub, you have to know, what is the size of the region. These things we will learn later.

And some they may not be very effective sometimes and you have to know the aerofoil characteristic in the sense in terms of C l, C d etcetera, when the flow is coming from trailing edge to the leading edge; that means you have to do an internal test. But, these are all lot of aerodynamic characteristics of the aerofoil they are required, when you are actually make into (( )).

But, when we use it when we actually design most of our analysis many things, we still take the 2 d leading edge to trailing edge only. But, the approximation we may make we may neglect that region, sometimes you may take the only the drag effect or lift view put it opposite you do anything; these are left your own ingenuity. But, they restrict the maximum speed the helicopter can fly; but, this is not the only region please understand this is one of the reasons, because there are several reasons which restrict the maximum speed a helicopter can achieve.

Because, there are only one helicopter which I think 400 kilometers are something like that that is all that is the maximum speed it has gone. That is only as a record; otherwise, most of them fly around 250, 280, 280 is a very high speed 280 kilometers per hour that is the high speed all right. But, one went around 400 something; because what will happen is this this is this region? If you keep on increasing V what will happen this omega, this region is going to be become bigger and bigger and bigger and this side will become in effective.

That is why when now I am going a little of, when you study helicopters there is you cannot say I fly at any speed. There is a non dimensional number you will learn it is only below this you can fly. But, if you want to analyze theoretically you can take that non dimensional any value, but it has no meaning as were as the helicopter, as a vehicle is concerned. That is why sometimes, even your research as a parametric study you can always say I will vary this parameter from 1 to 2, 2 to 3, 3 to 4 anything; but in reality, in the helicopters even, because there are some equations which I will introduce you later. It is an interesting equation, because which you will come across normally is in your course, just the flap dynamics and forward flight that is the equation.

And you will find for curiosity, you can change the forward speed to change to any value just to see how the solution looks; how the flap, not the how the helicopter blade flaps, how the equation gives the solution. That is interesting, but in reality you do not go to that region. Because, if you say when you write an article or anything you say oh this is useful for helicopters, no it is not useful for helicopters.

I saw I know some professor says, what he is talking about, he is talking some rubbish; what value he is taking? Because, that value is meaningless as far as the helicopters are concerned. So, we will also in this course, you find some and they will say, what range there are real helicopters operate, because that is very very important; because, it is not that any value you can take and then starting putting it.

Aircraft you can say subsonic, transonic, supersonic or hypersonic, you can take anything, here no. There is no supersonic, but transonic some regions are there that is in the blade, may be some sonic will come. But, the helicopter will not fly at supersonic speed or anything like that. If you want to make then we have to think how to make that is a different issue. So, our speeds are highly restricted right. So, please note that, we do not fly at any speed, there is a restriction.